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TITLE A Unified Approach to Science Teaching.
INSTITUTION Brown Univ., Providence, R.I.
PUB DATE Mar 70
NOTE 14p.; Paper Presented at Annual Meeting of the
National Association for Research in Science
Teaching (43rd, Minneapolis, Minne., March 5-8, 1970)

EDRS PRICE EDRS Price MF-\$0.25 HC-\$0.80
DESCRIPTORS *Curriculum, *Fused Curriculum, *Instruction,
*Science Education, Scientific Literacy

ABSTRACT

The purpose of this paper is to suggest the introduction into advanced secondary school and elementary college programs of courses of study which will emphasize science as a method for the description, creation and understanding of all aspects of human experience. Such a course will involve an examination of each category in the method, along with a wealth of illustrations from all branches of science. It will stress the nature of scientific theorizing, the historical development of scientific concepts, the behavior patterns of scientists, the unity of science, the relations of science with technology and the state, and the influence of science on human thinking and activity, past and present. Such courses will demand changes in the methods of training science teachers for the secondary schools, as well as some modification in the outlook of college teachers. Courses of study as are suggested are aimed at helping young people gain a better understanding of the meaning of science and its role in our civilization. (BF)

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A Unified Approach to Science Teaching

by

R. Bruce Lindsay

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The teaching of science in the schools and colleges of the United States has assumed increasing importance in the last quarter century. Few will question the vital role which science has played in the development of civilization. Though the popularity of this way of looking at human experience waxes and wanes with the tides of public fancy and the emergence of the many problems disturbing our social equilibrium, there seems little doubt that science will continue to remain a dominant factor affecting our attitudes to the world around us as well as the practical use of our environment.

The inhabitants of this country obviously need the clearest understanding of the nature of science and its role in society that our educational system can provide. With increasing frequency our representatives in state and national legislatures are called on to approve legislation involving the expenditure of vast sums of money on projects into which science enters vitally. These legislators need all the professional advice they can get; they also must themselves have enough appreciation of science to be able to make intelligent decisions. In our democracy they must pay attention to their constituents; but if the latter remain ignorant of what science and its related technology

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are all about, chaos may easily ensue. We are already seeing ominous signs of this possibility in the uncertainty and lack of assurance with which the Congress is approaching the vital scientific problems of the nation.

It is fortunate that the problem of improving science teaching in our educational institutions is not being ignored; the existence and vigorous activities of the National Association for Research in Science Teaching are a happy augury for progress in this direction. We can, to be sure, all agree that much remains to be done, even though there is no universal agreement on the optimal way of doing it. It is a great honor to me to be invited to speak at your meeting as one who has enjoyed many years of trying to teach physics and science in general to university undergraduates and graduate students. I come before you, indeed with diffidence, since I am not tutored in the professional arts of education and cannot pretend to any experience save in that educational "School of hard knocks" in which one never knows whether he has been successful until the game is all over and he can point to certain of his former students who have achieved professional success. Even here, satisfaction must be tempered by the realization that these clever people would have become successful anyway, even had they never known me!

It is necessary to emphasize that my talk will not be specifically concerned with the instruction of those who intend to become professional scientists. This in itself presents challenging problems. In physics, for example, the job now being done in the universities is not entirely satisfactory. The teaching tends to be narrow and parochial and there is too little emphasis on the unity of science and its relation to society.

Though this has some relevance to my story, it is not my chief concern. I wish to discuss the teaching of science as an inevitable, integral part of our culture to all who pass through our educational system.

I may as well state at the outset my conviction that the departmentalized teaching of science in both secondary schools and colleges is unsatisfactory for the general student. Departmental courses tend to be narrowly oriented, are often wasteful of time and can give a misleading idea of what science really is. In general they make little attempt to stress the fundamental unity of science and the important aspects of its role in civilization, its relation to technology as well as to other ways of looking at experience and its promise for the future.

Before we go more deeply into these educational matters it is necessary to say something about the nature of science. This may seem rather futile, when everyone, including the celebrated man in the street, is supposed to know what science is. However, there is still considerable confusion about this, in spite of the endeavors of first-rate popular expositors. Much of the confusion arises from the failure to distinguish science from technology. Now technology is a very important form of human activity, namely that devoted to man's endeavor to control his environment so as to make life more comfortable and interesting. This, though often closely related to and in our time more and more dependent on science, is not the same thing as science.

What, then, is science? It is an activity not easy to epitomize, but one can do it in the following fashion. Science is a method for the description, creation and understanding of human experience, where by experience we mean simply everything that happens to each one of us in every waking

moment of our life (perhaps even while we sleep) together with the reflections made on the happenings by the top end of the nervous system. It may be objected that this definition is not specific since it might equally well apply to the arts and the humanities. I agree and assert that this is a good feature. The definition becomes specific as regards science when we explain what the scientist means by the terms description, creation and understanding.

By description in science we mean the search for order or pattern in the midst of the flux of experience and then the talking about it in the simplest possible way. Thus, for example, we observe the regularity displayed by repetitive phenomena like the succession of day and night, the rise and fall of the tides, the changing of the seasons with the associated biological changes. Through closer observation we become aware of the existence of fairly precise relations connecting apparently diverse phenomena, as for example, electric current and magnetic field; pressure, volume and temperature of a gas; period of revolution of planet in the solar system and its mean distance from the sun. In another branch of science we note the relation between stimulus and response in a living organism. These relations ultimately take the form of scientific laws which, as we say, describe patterns in portions of our experience and to the setting up of which scientists have devoted relatively enormous efforts. Such laws have been developed in every part of science, from the Oersted-Ampere law in electricity to the Mendelian law of heredity in biology.

By the creation of experience in science we mean the production by overt human action of experience not hitherto evident by passive observation. This is carried out by a process known as experimentation, in which

the scientist deliberately decides to arrange certain portions of experience (by manipulation of actual objects, etc.) in a fashion not previously attempted, just to see what will happen. Experiment is thus one of the great categories of science. In countless laboratories throughout the world scientists are continually engaged in performing experiments of every conceivable kind to create new experience and thus add to human knowledge.

The most important element in science, however, is the third category, that of understanding. By this we mean the invention of theories representing the urge of the human mind to seek what we call an explanation of the regularities found in our experience. If description and creation try to answer the question: how do things go, theories are built to try to cope with the question: why do they go this way? A theory is a free creation of the human mind, involving the construction of concepts possibly suggested by experience but not necessarily connected therewith. It further involves the making of hypotheses connecting the concepts and finally the deduction from these hypotheses by logical thought processes of statements which can be compared and hopefully identified with observed scientific laws. If the identification can be carried out successfully the scientist says that he understands the corresponding experience better than he did before! the theory is successful. At first glance this may seem to be a rather curiously optimistic procedure as well as a dubious use of the word understanding. Perhaps we can make the situation clearer by means of a simple example.

The air in a room is a mixture of gases. So far as ordinary observation goes a gas is a fluid which flows like water in a perfectly continuous fashion. There seems at first little reason to endow it with a particulate

constitution. But from the continuum point of view it is difficult to account for the existence of pressure in a gas, that is, the force exerted by the gas on unit area of the walls of the surrounding container. Let us therefore construct a theory in which we postulate that the gas is really made up of a host of small particles (for long called molecules) moving with relatively large though varying velocities in all directions, bumping into each other and the surrounding walls. We further endow these molecules with mass. If then we are willing to assume that their number and speeds are sufficiently great we can explain the existence of pressure by the statistical effect of the collisions of the molecules with the walls of the container. Actually we go further and deduce by simple mathematical analysis a relation between the pressure and volume of the gas, which can be identified with the law of Boyle, whose content is that the pressure varies inversely as the volume if the temperature remains constant. This to be sure necessitates a further assumption: the temperature of the gas is somehow connected with the average speed of the molecules. To summarize, the assumptions of what is called the molecular (or kinetic) theory of gases lead by direct logical reasoning to deductions of the observed laws of gases.

Theorizing, then, is what the scientist means by understanding. Clearly this use of the term understanding hardly counts for much if a separate theory is needed for each element of experience. Actually the goal is to make theories general enough so that they explain as large a domain of experience as possible. Thus we seek to make the molecular theory able to account for the observed behavior of liquids and solids as well as gases. This result has been achieved. Moreover we want scientific theories to be able to predict experience not hitherto observed. Successful theories like the molecular theory and many others in all branches of science have been

able to do just this, and hence have justified our faith in their capacity to enlarge our grasp and genuine understanding of experience.

It is through this way of looking at science that we sense its fundamental unity. For all branches of science employ essentially this method, though the details may differ from branch to branch. Physics may employ the abstract symbolism of mathematics more than much of biology, but this scarcely affects the basic similarity in fundamentals. The theory of evolution has the same logical structure as the theory of gravitation. Moreover the view of science just set forth enables us to grasp more readily the utility of the concepts of one branch of science in other branches. For example, the concept of energy, which occupies the key position in the theory of thermodynamics, perhaps the most all-embracing theory of physics, has proved to be directly applicable to all other parts of science. Indeed there is no element of human experience which is not interpretable in terms of either the transfer of energy in one form from one place to another or the transformation of energy from one form to another.

This view of science has also the advantage that it enables us to see the similarities between science and other ways of looking at experience, namely the arts and humanities. At a time when it is fashionable to stress the alleged differences between the humanities and science and indeed enlarge on the so-called impassable gulf between them, it is important to call emphatic attention to the fact that the differences are not as great as the similarities. Artists and humanists in general also strive to describe, create and understand human experience and the ways in which they go about their business are not so different from those of the scientists as some would have us believe. Differences in detail there naturally are, but on

net balance they are outweighed by the basic similarities. All interpreters of experience are brothers under the skin. Recent literature has documented this point sufficiently so that it needs no further emphasis here.¹⁾ Realization of it has served to bring science closer to the realm of human values, where it ought to be. By the same token our view of science brings it closer to problems of human society both on the ideological and technological levels.

It is now appropriate to turn to a consideration of the kind of science teaching suggested by the previous considerations. In doing so I shall confine my attention to science instruction in the middle and secondary schools and in the so-called general education course in colleges. This does not mean a lack of interest in elementary school science teaching. On the contrary I think this is enormously important: the young child should begin to learn about science as soon as he learns about anything. However, I do not feel myself competent to enter this field.

Throughout the period which I am discussing science should be taught as a unit and not subdivided into the various branches called historically physics, chemistry, biology, etc. The emphasis throughout should be on science not just as a collection of facts, cheerful or otherwise, but on science as a carefully developed sequence of ideas or concepts, which the human race has found of value in its attempt to cope with experience. It may be said that I am apparently referring here to the general science course already in use as a vehicle of instruction in the middle school. I realize that courses of this kind have both praised and damned, probably more frequently the latter. With suitable modifications I think they are on the right track. It seems desirable indeed to eliminate the adjective "general", which serves no useful purpose save to invite attack. We ought

to strive to teach science, first and last, without qualification.

In the middle school emphasis should first be placed on description, and we should make sure that the student gets the idea that there are regularities in experience and that some which lie within the range of his own experience can be talked about in fairly simple fashion. It is important at this stage to choose examples of patterns from all branches of science and to indicate as simply as possible their interplay. Thus in discussing climate one would introduce not only the observed regularities with respect to the winds, atmospheric pressure and precipitation but also the role of climate in the growing of food and human economy generally. I need hardly stress the absolute necessity for encouraging the young to exhibit and strengthen their curiosity about the way things go on every level of experience.

At this descriptive stage it should also be possible to introduce some important scientific concepts in terms of their operational definition. One could, for instance, cite the operational definition of the volume of a solid as provided by Archimedes in his bath tub; similarly the concept of inertia introduced by Galileo in his endeavor to replace Aristotelian mechanics by something more imaginative but at the same time more closely related to actual experience. One could go on to call attention to some chemical elements obvious in common experience, compare them with compounds and refer to the epoch-making contributions to this field by the Honorable Robert Boyle. Not to leave out biology, one would refer to the concept of heredity and bring in Mendel and Galton. In each case the aim would be not only to make the concept meaningful in its simplest sense in terms of the ordinary experience of the young student but also to bring out the fact that it has had a history--it was made by human beings

who were searching for a more meaningful grasp on experience.

The above discussion of the role of description inevitably suggests experimentation and the importance of its introduction at an early stage of science teaching. Here the student must be led to grasp the idea that in performing an experiment he is literally creating new experience--new at any rate to him. How to accomplish this effectively involves a lot of educational experimentation. The optimum scheme probably is to turn each student loose with a lot of simple equipment and tell him to exercise his curiosity and ingenuity by finding out everything he can. For some students this might well be the beginning of a life time interest in science, but it is clearly expensive and tough on the teacher. Guidance is necessary to avoid chaos, but if this guidance leads to the imposition of a cook-book recipe type of approach to experiment, the result can ruin any genuine appreciation of what science is about.

This emphasis on description and creation should continue through the yearly science courses right to the end of the secondary school. But in the final two years it should be supplemented by a consideration of the category of understanding--the building of theories. This is by far the most difficult part of the job, for theory building is the most abstract element in science. Yet there is no reason why young people in the age range from 15 to 18 should not grasp the significance of the use of the imagination in science, for that is the key idea. It is essential to stress the role of hypothesis--educated guessing--in the construction of scientific theories and to make clear the freedom which the scientist has in the invention of hypotheses, a freedom wholly similar to that of the artist in the creation of his works. Illustrations should be investigated from all branches of science. Particular emphasis should be placed on those theories

whose range of application extends beyond the narrow confines of one branch. Much attention should obviously be paid in this context to the atomic theory, which provides understanding of a vast domain of experience in physics, chemistry and biology. Similarly the theory of thermodynamics must be considered, since its field of application is really the whole of human experience. It is commonly believed that thermodynamics is narrowly restricted to mechanical engineering, physical chemistry and chemical engineering, but this is a complete misapprehension, and even the high school student can be made to see it. Relativity and quantum theory obviously pose greater difficulty, but some understanding of these can be achieved in the secondary school, with of course more emphasis in college. The various theories of psychology (behavioristic, introspectional, sensory perception, etc.) should come in for attention. Of course the great theory of evolution in biology is an essential part of any science program. Here the teacher should direct attention not only to the evolution of forms of plant and animal life but to cultural evaluation as well, thus serving to provide a vital bridge between science and the social and humanistic studies.

Throughout the program historical perspective should not be lost sight of. This is usually slighted in the conventional science courses in secondary school and college. This, of course, means more than merely mentioning the names of some celebrated scientists and introducing an anecdote or two about them. It means some exploration of the psychology of scientific invention, an attempt to understand the motivation of the great scientist and the methods he used in obtaining his ends. Even more important is emphasis on the slow and often painful way in which the important concepts of science have evolved. The uphill struggle of the Copernican heliocentric

theory of the structure of the solar system against the geocentric theory could be cited; likewise the struggle of the theory of evolution and the germ theory of disease in biology. This concern provides an opportunity to stress the role of the contemporary political and cultural environment on the development of science and the painfully won victories of rationalistic science over ill-founded superstition. Examples abound, but the current resurgence of astrology suggests an appropriate point to hammer home.

Now it is not at all difficult to criticize adversely the program above suggested. One can think of half a dozen points at least about which to raise objection. I shall confine myself here to a consideration of two which I am sure all teachers will raise. The first is the inherent danger of superficiality. By making the unity of science the key to the whole program and thus making sure that all branches of science are included in a single package in each annual unit of instruction, how can one avoid spreading the treatment too thin to achieve meaningful results? This hazard certainly exists, but it is based principally on an interpretation of science teaching which I cannot accept, namely that the only worthwhile science teaching is teaching in depths, i.e., that in which the student is expected to master the details of the subject so that he can actually handle it professionally. To me it just does not seem sensible to try to teach science in this way to high school and the large majority of undergraduate college students, that is, those who are not planning professional careers in science. What we should have as our aim is do our best to make sure these students grasp what science is about. We have to sell a point of view which has been and continues to be of enormous significance in the cultural history of our race. It seems to me that this is a far more im-

portant thing to do for our students than to train them technically in scientific techniques. We are indeed permitted to hope that the kind of program here envisaged will motivate certain able students to want to know more about science and to become scientists themselves. Their further education in this field can safely be left to them under the guidance of our professional scientific colleagues.

The second criticism I have in mind, and from a practical viewpoint a much more serious one is this: who will teach such courses? Will not the prospective teacher have to demonstrate unusual breadth both of knowledge and pedagogical skill? I suppose the answer must be yes, and this means ultimately a broader type of teaching training, with more hospitality toward the fundamental unity of science. More elaborate use of teacher aids will also be necessary. Fortunately this does not pose serious problems, for audio-visual aids in the form of films, etc., are now available in profusion. It should be possible to persuade distinguished experts to tape lectures on the broader aspects and make them widely available. Programmed instruction, now widely being experimented with, might also be brought into the picture.

Any educational program involves difficulties. Genuine teaching has always been and will remain a tough job. I do not wish to leave the impression that the difficulties associated with the program discussed here can be casually dismissed. Even if it does not succumb to devastating criticism on technical pedagogical grounds, it will be undoubtedly hard to sell it to professional scientists and their organizations, not to mention school and college administrators. The former with their devotion to research tend to develop narrow parochial attitudes rather

inhospitable to experimentation in science teaching. The attitudes of the latter are doubtless sufficiently well known to members of the National Association for Research in Science Teaching to need no further comment here.

On my side of the fence I fear that my ideas will secure scant sympathy from professional physicists, chemists and biologists. Hence if experimentation along these lines is to be initiated and further developed, its promotion must be in the hands of those professionally interested in science education. That is why I have appreciated so much the opportunity to share my ideas with members of the National Association for Research in Science Teaching. I believe these are the only people who can ultimately bring about such innovations as I have in mind. I earnestly solicit all the criticism I can get.

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